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MOBILE MEDICAL MONITORING AT FORWARD AREAS OF CARE

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Summary

Problem

The nature of the U.S. Marine Corps mission is changing. In addition to combat operations, Marines are increasingly committed to a broader range of support scenarios and operations other than war, including humanitarian and disaster relief efforts. These commitments require a greater medical support with limited patient information, diagnostic tools, and logistic support. It has been suggested that new and emerging technologies can be used to prepare responders for this challenge.

Objective

The objective of this report is to document the requirement for mobile medical monitoring in the Marine Corps. Mobile medical monitoring for forward deployed forces could be used to perform continuous monitoring of patients while they are waiting to be treated and evacuated. Providing miniaturized, lightweight, compact, ruggedized emergency medicine and medical information technology tools could improve the ability of on-scene personnel to save lives and sustain the numbers of able-bodied staff required for mission accomplishment. In view of the many potential uses for mobile medical monitoring, it is important to identify the optimal suites of tools (medical sensors, equipment, and software) for deployment in support of specified U.S. Marine operational scenarios.

Approach

Multiple data sources were used for determining the requirements for future evolutions of a Mobile Medical Monitor (M3) capability. Survey data were collected from 63 respondents from various medical exercises. The survey consisted of questions regarding the M3 (A) and possible features for future evolutions of the M3. Data were also gathered using a series of matrices about medical sensors and monitors that would be useful in various operational scenarios. Discussion groups were conducted with subject matter experts as a means to gather more information. Medical doctrine and policy documents were reviewed and analyzed as another source for requirement definition. Information based on the medical supplies used at a far-forward medical treatment facility was also reviewed.

Results

The results from the multiple data sources revealed several requirements for an M3 capability. Three types of medical functions were identified: clinical functions, clinical support functions, and administrative functions. Seventeen different functions were recommended as requirements. ECG monitor, pulse oximeter, blood pressure, temperature, ultrasound, and digital x-ray were recommended as clinical sensors, while multi-patient monitoring, Smartcard reader/writer, electronic patient record, and image capture were mentioned as clinical support functions. Also, the ability to

transmit patient information using store and forward techniques was indicated by multiple data sources as a beneficial capability.

Discussion and Recommendations

The results of this work should guide the evolution of the next prototype, the M3 (B) workstation. Two separate paths will be used to achieve the clinical, clinical support, and management support functions. One path will focus on the requisite clinical and clinical support functions. The other path will address the development of a multi-patient monitoring capability.

Thus, the M3 is being fielded using an "evolutionary integration" approach that allows the development of the M3 (B) clinical and communication capabilities while the multi-patient monitoring functionality can be explored. This approach uses and integrates existing off-the-shelf technologies to meet emerging requirements of field medical units.

Introduction

The nature of the U.S. Marine Corps mission is changing. In addition to combat operations, Marines are increasingly committed to a broader range of support scenarios and operations other than war (OOTWs) including humanitarian and disaster relief efforts (Horne, Carey, & Rattelman, 1995; Horne, Carey, & Rattelman, 1996; Reed, Martino, & Pugh, 1996). These commitments require medical support, often in remote and austere environments. The requirement to operate at a fast, fluid pace in these complex environments with limited patient information, diagnostic tools, and logistic support places unusual demands upon medical responders in the field (Horne et al., 1995; Horne et al., 1996). Consequently, early recognition of symptoms and proper diagnosis can mean the difference between return to duty or medical evacuation and, more importantly, the difference between life and death.

New and emerging technologies can be used to prepare responders for this challenge. Providing miniaturized, lightweight, compact, ruggedized emergency medicine and medical information technology tools for use by responders and medical providers in forward units or in remote locations with limited medical resources can improve the ability of on-scene personnel to save lives and sustain the numbers of able-bodied staff required for mission accomplishment (Gauker, Pugh, & Pearsall, 1995; Gorman, 1996).

Mobile medical monitoring for forward deployed forces could be used to perform continuous monitoring of patients while they are waiting to be treated and evacuated. Also, future deployed units will require enhanced medical monitoring capability when casualties must be held for extended periods. Physicians and corpsmen inexperienced in field medical conditions might derive benefit from greater availability of diagnostic equipment (Roberts, 1992).

Historically, Marine Corps casualties have been moved from the battlefield, and care has been provided in a progressively phased health care system (echelons of care) that extends from the point of battlefield injury through theater medical treatment facilities (MTFs) and ultimately to continental U.S. hospitals. The forward facilities are highly mobile but have limited medical capability, while higher level facilities toward the rear are less mobile but are highly capable. The system's effectiveness is measured by its ability to save life and limb, to reduce disease and nonbattle injury (DNBI) rates, and to return patients to duty quickly and as far forward in the theater as possible. The capability for medical support in remote environments is becoming more urgent because of the evolving nature of Marine Corps operations, as expressed in Operational Maneuver From The Sea (OMFTS), the growing threat of chemical and biological weaponry, and the increasing number of requests for the Marine Corps to provide drug interdiction, humanitarian support, and disaster relief assistance. Under the OMFTS concept, the tempo is expected to increase, making patient screening and casualty triage even more difficult. Marines are likely to be highly dispersed and very mobile; therefore, casualties may occur in scattered pockets. These conditions will necessitate greater mobility of forward-deployed units, requiring medical support teams to be lighter and farther apart.

Because of advances in microtechnology, much of conventional emergency medicine will be replaced by a mobile capability: miniaturized, portable equipment that travels to the patient. Mobile technology can deliver more advanced care at sea and ashore. It increases medical capability and reduces the need to evacuate patients.

Emergency medical care can have a profound impact on ultimate casualty morbidity and mortality. For more complicated emergencies that cannot wait for transportation to the rear, more sophisticated resources are needed. Trauma in remote areas constitutes a complex process, complicated by the inadequacy of patient histories, diagnostic modalities, and logistic support and further challenged by the increasing pace of operations. Early diagnosis and appropriate treatment may significantly influence the outcome of these casualties.

A mobile medical unit would offer the capability to not only collect, display, store, and transfer current patient information but it would also provide access to medical specialists and past medical information. Such a unit would facilitate the delivery of care sooner, thereby saving lives, improving long-term function, facilitating triage decisions, and returning troops to duty faster.

Objective

This study is one part of the evolutionary integration of the mobile medical monitoring concept. A prototype unit, called the M3 (A), is the focus of this effort. The objective of this report is to document the information gathered to determine the Fleet Marine Force (FMF) requirement for mobile medical monitoring and to outline the potential capabilities of the next version of the M3. Recently, a variety of noninvasive medical diagnostic sensors have been developed. Since there are many potential uses for mobile medical monitoring, it is important to identify the optimal suites of tools (medical sensors, equipment, and software) for deployment in support of specified U.S. Marine operational scenarios.

Mobile Medical Monitor

A basic mobile medical monitor, the M3 (A), was used for demonstrations and field exercises. It consists of three commercially available, FDA-approved, noninvasive vital sign monitoring devices (sensors) integrated into a ruggedized, portable, lightweight computer unit used by the military. The devices consist of a blood pressure (BP) cuff, a pulse oximeter, and a 12-lead ECG. In addition, a video camera is connected to the computer to capture images of injury sites. The computer, shown in Figure 1, displays, stores, and forwards these images and the vital signs data.

Additional candidate technologies that have been proposed for satisfying the clinical requirements for improving the ability of medical personnel to rapidly diagnose and treat casualties include: ultrasound with Doppler; digital x-ray, blood gas assessment; general scope/nasopharyngeal, and temperature. Other capabilities that optimize the efficient use of the physiological sensors include a multi-patient monitoring capability, an interface with data card technology, imaging capability, and a global positioning system. The usefulness of these clinical sensors and clinical

support functions for providing far-forward medical care will be evaluated.

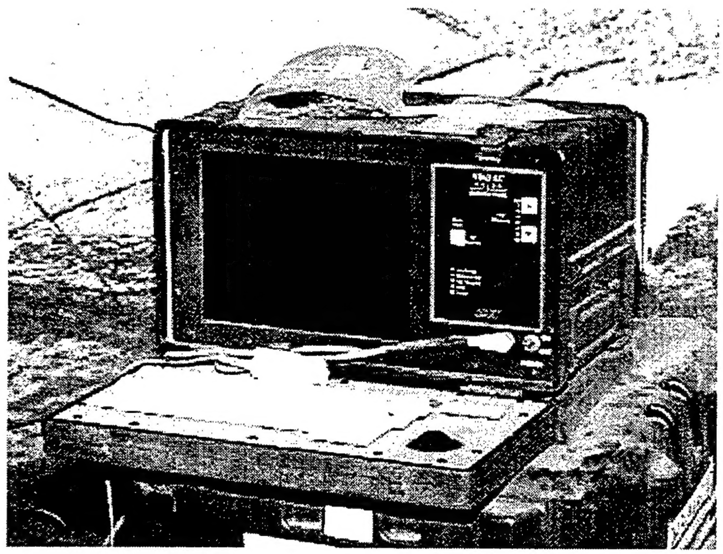


Figure 1. Mobile Medical Monitor, M3 (A) consists of a rugged computer and three vital signs sensors.

Method

The current study used a combination of data collection methodologies to derive the requirements for the next prototype, the M3 (B) configuration. The data sources included warfighting doctrine, medical resource requirements, user survey results, and experience contributed by operational personnel. The strength of this data collection methodology is in the combination of different data sources (Miles & Huberman, 1994; Patton, 1990). The value of using multiple data sources is in the triangulation or convergence of the information. When asking the same question of different sources of evidence, if all sources indicate the same answer, then there is success in the triangulation of data (Yin, 1993).

Data Collection Instruments and Procedures

As discussed earlier, Patton (1990) stated one important way to strengthen a study design is through triangulation or the combining of methodologies in the study of the same program. Denzin (1978) identified four basic types of triangulation: data, investigator, theory, and methodological. The current study employed three of the four methods of triangulation just mentioned. The use of multiple perspectives, those of the various stakeholders (i.e., doctors, nurses, corpsmen, dental technicians), is considered theory triangulation. The use of multiple data sources, warfighting doctrine, medical resource requirements, user survey results and subject matter expert feedback is considered data triangulation. Finally, both qualitative data and quantitative data were used, which

is an example of methodological triangulation. The following section contains information about the data collection instruments and the procedures used to obtain the data.

Marine Corps Doctrine

Meeting the demands of current and emerging doctrine for Marine Corps medical units requires improvements in existing medical technology. Concepts such as OMFTS have resulted in changes in how and when medical units are employed. Documents were reviewed to gather requirements for the technologies that should be incorporated into a mobile medical monitor. The main document used was the Forward Resuscitative Surgery Seminar (1997) report. This seminar was sponsored by J-4, Medical Readiness Division, and the Commandant's Warfighting Laboratory, U.S. Marine Corps. The forward resuscitative surgery (FRS) concept is envisioned as the initial emergency medical response to those critically injured in combat. FRS is a major component of Joint Health Services Support Vision 2010. Participants in the FRS seminar included military and civilian trauma surgeons. Using a case study methodology, they defined FRS treatment protocols. Discussions regarding the medical requirements focused on clinical issues, medical doctrine, training, research and development, and material development. Specifically, they considered developing technologies that could be applied to improve surgical resuscitation.

Medical Resource Requirements

The Naval Health Research Center (NHRC) has developed a model for the U. S. Marine Corps that estimates medical supply and equipment requirements for forward echelons of care (Galarneau, Mahoney, Konoske, & Emens-Hesslink, 1997a; Galarneau, Konoske, Emens-Hesslink, Pang & Gauker, 1997b). Clinical subject matter experts (SMEs) with operational experience assisted in the development of Marine Corps specific treatment profiles for the 350 Deployable Medical Systems (DEPMEDS) Patient Conditions (PCs). The PCs reflect the range of injuries and DNBI known to occur in theater. From these treatment profiles, the specific medical tasks performed for each PC were identified. Then the SMEs assigned supplies and equipment needed to perform each task establishing a clinical requirement for each piece of material. This model links each supply item to a specific clinical requirement. Information regarding the specific treatment profiles and the medical tasks was used to identify the types of supplies and equipment needed at far-forward levels of care. The surgical procedures conducted at forward levels of care are listed in Table 1. Using this information, the need for vital signs monitoring was determined.

Table 1

Surgical Procedures

Amputation through lower arm/leg	Repair kidneys
Bowel closure/resection	Repair urinary bladder
Burr hole	Repair neck structures
Complete nephrectomy	Splenectomy
Escharotomy	Thoracotomy
Fasciotomy	Tracheostomy
Operation to liver (not resection)	Vascular repair-temp/ligate

Survey of Marine Corps Medical Personnel

The survey respondents were medical professionals who participated in several military medical exercises (i.e., Tandem Thrust '97, Hunter Warrior '97, and Kernel Blitz '97) and other exercises created for the M3 project, and they were members of the 1st Medical Battalion, Camp Pendleton. The medical exercise personnel were classified into five categories: medical doctors, nurses, corpsmen, dental technicians, and other (e.g., Medical Service Corps officers).

The survey of M3 (A) users combined dichotomous, multiple choice, rank order, and open-ended questions. The 18-question survey took approximately 10 minutes to complete. The first part of the survey consisted of demographic questions. The second part pertained to the usability of the M3 unit. The main questions for this study related to the vital sign measures and features of the M3 (A) that the respondents believed should be added to future M3 evolutions. A copy of the survey is in Appendix A

Matrix Data Collection Form

The matrix data collection form was structured to collect ratings of usefulness of the medical tools, sensors, and physiological measurements depending on the scenario type and level of care. Three types of missions were provided: Standard Combat, OOTWs, and OMFTS. Four levels of care were provided: Front Line, Battalion Aid Station, Shock Trauma Platoon, and Surgical Company. The respondents were asked to suggest other levels of care or other medical tools, sensors, and measurements, and to fill in the appropriate responses. The form took approximately 20 minutes to complete. A copy of the matrices is in Appendix B.

Site Visits/Discussion Groups

Site visits were conducted at the 1st Medical Battalion to gain perspective on the operation of the unit and to collect qualitative information not available through other sources. The visits were also conducted to gather feedback from the 1st Medical Battalion personnel on the M3 (B).

The discussion group participants were SMEs in the area of combat casualty care. At one of the discussion groups, NHRC personnel provided the 1st Medical Battalion personnel with a description of a potential M3 (B) and Multi-Patient Monitoring system. A nonstructured format for feedback was used to elicit information from the group participants.

Results

Marine Corps Medical Doctrine

The 17 case studies from the FRS Seminar report were reviewed, and the medical technology recommended for each of the cases was described. The case studies included serious trauma injuries resulting from mine blasts, flechette fragments, mortar fragments, and gunshots. All cases required surgical intervention. Each case was evaluated and discussed regarding the surgical challenges, the streamlined treatment approach, the technology requirements, and the training and education requirements. The type of technology suggested for use in each of the 17 case studies was evaluated.

New medical technology was recommended for use in 10 of the 17 case studies. Ultrasound was the most frequently suggested new technology. It was suggested that in 6 of these 10 cases ultrasound would be very useful.

Since all of the cases in the FRS report required surgery, ECG, pulse, O_2 saturation, blood pressure, and temperature are supported. Two cases required x-ray series. They recommended some type of miniature, digitized x-ray for the treatment and evaluation of extremity wounds and thoracic injuries. One FRS case indicated that information regarding blood gases was an important measure.

The FRS participants concluded that problems could be anticipated if an automated method of monitoring vital signs were included. Further, they suggested that medical capability could be greatly enhanced if they were able to monitor multiple patients. The FRS participants noted that the large amount of data generated during the care of FRS patients needs to be transferred with the patient to the next attending physician or hospital level. Information regarding treatment, therapies, surgical condition, and diagnostic criteria must be encapsulated with the patient and kept as part of an overall medical record to be easily transported throughout the continuum of care.

When the participants were asked to rank the 14 FRS requirements, a portable, forward surgery module was fourth, while the ability to have noninvasive imaging capability was ranked fifth. Capturing and transferring patient data were ranked seventh. In general, the seminar highlighted the need for noninvasive, accurate diagnostic techniques to assist in the early evaluation of severe penetrating and nonpenetrating injury to the head, thorax, abdomen, and extremities.

Medical Supplies: Marine Corps Authorized Medical Allowance Lists (AMALs)

Medical supplies used at far-forward Marine Corps medical facilities (Galarneau et. al., 1997a, b), were analyzed to determine the type and usage of patient monitoring equipment. The

analysis involved reviewing the types of PCs that arrive at forward area medical facilities and the treatment tasks (surgical procedures) involved with each of those PCs. The supplies and equipment required to perform each surgical procedure was determined. Table 2 shows the surgical procedures that are conducted at a forward medical facility and the number of PCs that involve each of those treatment tasks. Of the 350 DEPMEDS PCs, 72 PCs involve one or more surgical procedures. Twenty six PCs require more than one surgical procedure.

Table 2

Patient Conditions Involving Surgical Procedures
at a Forward Medical Treatment Facility

Surgical Procedure	Number of Patient Conditions Requiring Surgical Procedures
Amputation	14
Burr hole	10
Bowel closure/resection	13
Complete nephrectomy	3
Escharotomy	5
Fasciotomy	2
Operation to liver (not resection)	8
Repair kidneys	4
Repair urinary bladder	10
Repair neck structures	2
Splenectomy	7
Thoractomy	3
Tracheostomy	4
Vascular repair-temp/ligate	13
Number of Patient Conditions	98

The equipment contained in the Marine Corps AMALs for far-forward MTFs related to M3 devices is as follows: battery-operated defibrillator, battery-operated vital signs monitor, battery-operated pulse oximeter, battery-operated intracompartment pressure monitor, ultrasonic unit with Doppler for the detection of blood flow, radiology equipment, and laboratory equipment. The vital signs monitors and the defibrillator contain ECG monitoring capability. The vital signs monitors also gather pulse, O_2 saturation, BP readings, and temperature readings.

Survey

The survey data were collected January to June 1997 primarily at field medical exercises. Sixty-three medical professionals participated in the current study. There were 31 corpsmen, 12 doctors, 10 nurses, 3 dental technicians, 2 Medical Service Corps members, and 5 people who did

not provide occupational data. The respondents indicated being in the medical field, on average, for 12.05 years. The average number of years in their current positions was 5.48 years. The respondents observed or used the M3 (A) device in a variety of settings, with the vast majority of respondents using the machine at Camp Pendleton during medical exercises. Ten percent of the survey data were from the Tandem Thrust '97 exercise, and 13% were from Hunter Warrior '97.

When asked to rank order the usefulness of the clinical capabilities of the M3 (A) the respondents indicated that blood pressure was the most useful measure. Oxygen saturation and pulse rate were the next two highest rated clinical capabilities for usefulness. The ECG/EKG and the still image capture were rated the lowest. Table 3 shows the mean rank for each clinical capability.

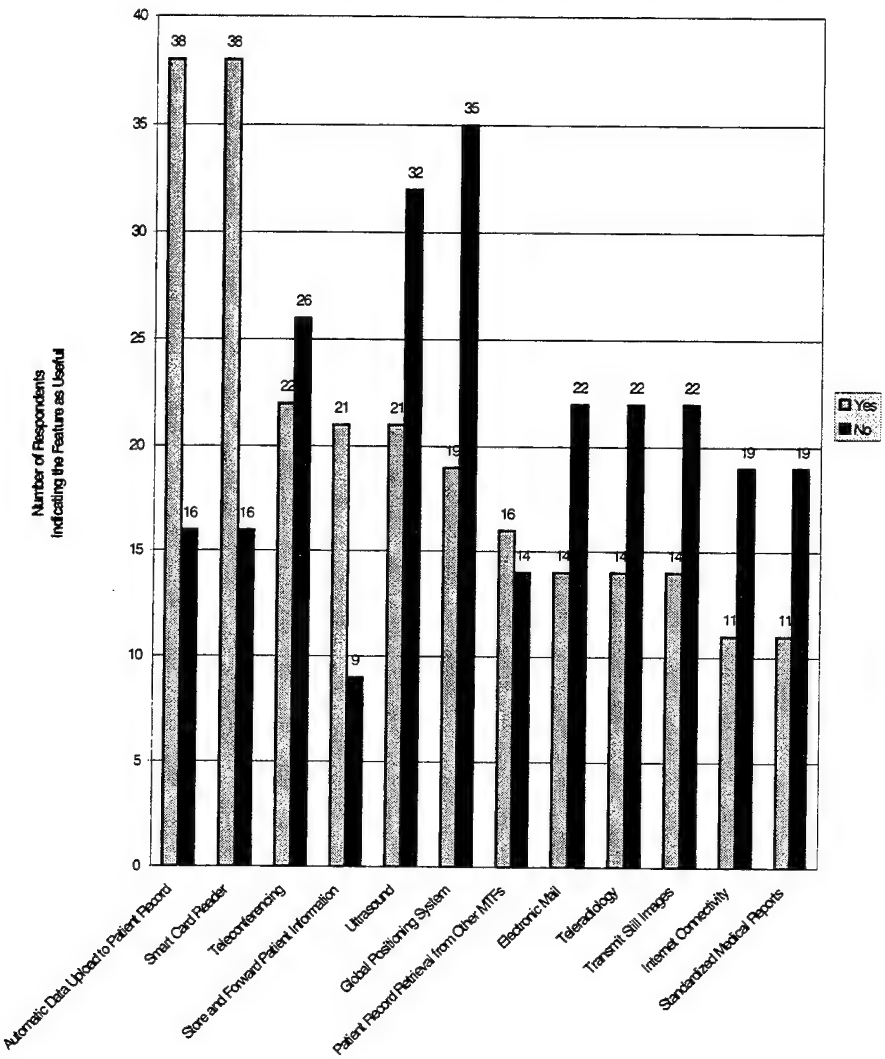
Table 3
Usefulness of Current M3 (A) Measure

Current Measure	Mean Score (5 = Highest and 1 = Lowest)
Blood Pressure	4.18
O_2 Saturation	3.40
Pulse Rate	3.33
ECG/EKG	2.67
Still Images	1.60

The respondents were asked to list additional capabilities (Appendix A, item 12) that would make the M3 concept more useful. Having automatic temperature input was mentioned eight times. Visual and auditory alarms, the ability to perform blood type/chemistry tests, and the ability to generate hard-copy printouts were each mentioned four times. The ability to transfer data and monitor multiple patients were mentioned three times, while performing ultrasound was mentioned twice. Capabilities receiving one comment each included a defibrillator, glucose monitor, patient location and tracking, pH monitors, simplification of the M3 (A) image capture and storage into patient folder, and x-ray capability.

The survey respondents were also asked to indicate which features would make the M3 more useful. The results of this question are shown in Figure 2.

Figure 2
Features Reported to Make M3 (A) More Useful



The survey results indicated that the ability to use Smartcard technology would be useful to the M3 (A). A Smartcard is a plastic card, similar to a credit card, with an embedded, updateable computer chip. The Smartcard, which is one type of field data carrier being employed, can be used for patient administration, for treatment documentation, and for communicating medical information between medical facilities. More than 70% (38 out of 54) of the respondents answering the question said having Smartcard technology would be useful. The ability to have some form of an electronic patient record received the most positive hits from the survey respondents. The only other features that had similar responses were Smartcard

reader, as previously mentioned, and the ability to store and forward patient information (70%, 21 out of 30 respondents).

Although survey participants previously indicated that an ultrasound unit would be a beneficial measurement tool, the responses to item 12 indicated that respondents did not feel that ultrasound capabilities would be useful. The Global Positioning System (GPS) received the most negative responses of any feature. Thirty-five respondents out of the 54 who answered the question indicated that GPS would not be useful; however, 19 respondents felt that it would be useful.

The majority of the survey respondents (81%) who operated the M3 (A) indicated that the unit was easy or very easy *to learn how to use.* Only 2% of the respondents found the unit difficult to use. When asked how easy or difficult the M3 (A) was *to operate,* 71% of the respondents reported it was either easy or very easy to operate. Twenty-two percent gave neutral answers, while 7% found it difficult. Seventy-nine percent of the survey respondents who operated the M3 (A) also felt that it was easy or very easy *to understand the data displayed on the unit.* Five percent found it very difficult to understand, while the remaining respondents provided neutral responses. Sixty-seven percent of the survey respondents who operated the machine found it easy or very easy *to read the data displayed* on the M3 (A); however, 10% found it either difficult or very difficult to read the data displayed.

Matrices Data

Thirteen respondents completed the matrices: 2 doctors, 4 nurses, and 7 corpsmen. These data were analyzed to determine the priority level of each of the medical sensors and/or measurements at the Surgical Company and fleet hospitals. A thermometer was the item most frequently listed as being a useful additional measure for the M3. It received the most comments (8), which is at least twice as many as any other suggested measure. The respondents indicated that ultrasound would be moderately useful. Heart rate, blood pressure, and O_2 saturation were again ranked very high as being useful sensors/measures. One respondent indicated that a 3- or possibly 12-lead ECG would be beneficial at forward MTFs. Although blood gases was not specifically listed on the matrix, the ability to conduct blood type and crossmatch was indicated as moderately useful. The data indicated that x-ray and a defibrillator would be moderately useful at a surgical company or fleet hospital. The addition of a Smartcard reader, a device that can read a Smartcard, was rated as somewhat useful. One of the respondents commented that if the M3 (A) could not completely replace all handwritten work, it would be more trouble than help. The respondents ranked video imaging as a highly useful feature. A patient location function was indicated as somewhat useful, while no one indicated that the existing user interface needed to be improved.

Site Visits/Discussion Groups

Discussion groups and meetings were conducted with SMEs. Preliminary survey data from the survey and FRS report were presented, and discussions were conducted regarding the

sensors/features that should be included on the next evolution of the machine. The SMEs were asked to comment on the relevance of the recommendations derived from the data and to offer any additional input.

The SMEs suggested that ultrasound with Doppler would be a beneficial measure to add. They suggested that at forward areas of care a 12-lead ECG would probably not be used as often as a 3-lead ECG. Pulse oximeter, blood pressure, and temperature were also suggested as very useful vital signs measures.

The SME participants further suggested that a nasopharyngeal scope would be an excellent addition to the current M3 (A). Their recommendation was based on trying to provide a good scope with multiple capabilities and thereby eliminating the necessity to carry many scopes with a single device. The SME discussion group also generated the recommendation to conduct blood gas assessments. These participants suggested that this information would enable them to make treatment decisions that would not be possible with simple O_2 saturation data.

The ability to perform multi-patient monitoring, however, was the single most important capability of any future units that might be developed. This group was very adamant on this requirement for future machines. Finally, the SMEs felt that it was important to have a patient record that could be stored and forwarded. The SMEs also stated that although GPS location was not a high priority, it would be useful. One of the participants commented that this feature would be more helpful on a helicopter or Shock Trauma Platoon, but not as necessary for a fixed facility.

Discussion

For the following discussion, the medical sensors and functions have been categorized in the following three areas: clinical functions, clinical support functions, and administrative functions. Included in the clinical functions category are those clinical applications that directly impact the ability of medical personnel to rapidly diagnose and treat patients. The clinical support functions are those features that might be described as "force multipliers." They include the ability to monitor multiple patients and to automatically record and aggregate patient information. The administrative functions allow the user easy access to databases and provide a communication capability. Table 4 provides a summary of the results. The X's in the cells indicate that the medical sensor/function is supported by the individual data source.

Table 4
Requirement for Each Medical Sensor/Function based on the Data Source

MEDICAL SENSOR/FUNCTION	DATA SOURCE Survey	Matrices	Site Visits/ Group Discussions	AMAL	Doctrine Documentation[d]
Clinical Functions					
Ultrasound with Doppler	X[a]	X	X	--	X
ECG monitor and diagnostic software	X	X	X	X	X
Pulse oximeter	X	X	X	X	X
Blood pressure	X	X	X	X	X
Temperature	X	X	X	X	X
General scope/nasopharyngeal	--[b]	--	X	--	--
Blood gas assessment	~[c]	~	X	--	X
X-ray (digital)	X	X	--	X	X
Defibrillator	X	X	--	X	--
Clinical Support Functions					
Simultaneous multi-patient monitoring	X	--	X	--	X
Smartcard reader/writer	X	X	X	--	--
Electronic patient record	X	X	X	--	X
Image capture	X	X	X	--	X
Global Positioning System	--	X	X	--	--
Administrative Functions					
Medical management/store and forward capability	X	X	--	--	X
Graphic user interface	X	--	--	--	--
Windows NT	--	--	--	--	--

[a] "X" = indicated as being useful
[b] "--" = not indicated as being useful
[c] "~" = supported as blood type and chemistry
[d] Forward Resuscitative Surgery Seminar

Clinical Functions

Ultrasound with Doppler. Ultrasound and Doppler technology provides an indirect noninvasive method of determining the presence or absence of blood in body cavities, vascular integrity, and location of shrapnel/missile fragments. Ultrasound and Doppler have proved to be of great value in early examination, diagnosis, treatment, and triage of combat casualties. As indicated in Table 4, 5 of the 6 data sources supported ultrasound.

ECG Monitor and Diagnostic Software. ECG monitoring is a standard diagnostic tool for many patient conditions. The immediate analysis of cardiac rate and rhythm are crucial in the analysis of all trauma patients and in the performance of all Advanced Cardiac Life Support and Advanced Trauma Life Support protocols. Interpretive (also called diagnostic) software for the ECG monitor, along with a store and forward capability, provides significant enhancement to the consultative capability and is vital for robust patient evaluation, treatment, and evacuation. ECG, one of the features resident on the M3 (A), was supported as being useful in all of the data sources.

Pulse Oximeter. The standard pulse oximeter provides immediate and continuous readings as a percentage of oxygen in the blood and permits monitoring during oxygen therapy. Prompt oxygenation is crucial to prevent brain injury during trauma and is a useful adjunct in the patient who is intubated and ventilated with supplemental oxygen. Pulse and O_2 saturation are combined in an original capability of the M3 (A) in the pulse oximeter. The capability of measuring pulse and O_2 saturation was supported as being useful in all of the data sources.

Blood Pressure. Blood pressure is important to assess the perfusion of peripheral tissues and the brain. Most often in emergencies, blood pressure can signal the presence of circulatory collapse or shock and indicates that fluid resuscitation is necessary. The ability to get a BP reading, a capability resident on the M3 (A), was supported as being useful in all of the data sources.

Temperature. Temperature monitoring is a standard and acceptable technology currently used in many monitoring systems. Core temperature is a useful indication and warning of hypothermia. In addition, temperature elevation can signal early detection of infection, which has a very high mortality rate. Elevation in temperature can therefore prompt the administration of antibiotics, which can help prevent septic shock. The ability to collect temperature data was not an original capability of the M3 (A), however, all of the data sources indicated it as an important measurement for critical care assessment.

General Scope/Nasopharyngeal. Using fiber optic technology to view, capture, and transmit images provides a minimally invasive procedure for a variety of clinical situations. The use of a minimally invasive scope can greatly augment the evaluation and extent of penetrating injuries to the extremities, chest, and abdomen. Shrapnel and bullet wound paths can be evaluated, and presence of active internal bleeding can be detected. In addition, direct laparoscopic visualization can be useful for minimally invasive surgical procedures.

The surgeons in the field medical units discussed the use of a nasopharyngeal scope as a general scope. Because it could be used in many ways, a general scope was suggested instead of having many different scopes carried with the unit. As can be seen in Table 4, the use of the nasopharyngeal scope was supported in SME discussion groups only.

Blood Gas Assessment. Indirect or minimally invasive methods of measuring blood gas physiology were identified as requirements from the FRS Seminar and the majority of all the surgeons (SMEs) in the field medical units. Those surgeons who felt it was a requirement said the ability to achieve blood gas assessments in the forward echelons of care and remote locations was critical in managing trauma patients. The SMEs said that they would be able to use the information from the blood gas assessments to monitor the shock process. As Table 4 indicates, two of the data sources suggest that the ability to do blood gas assessment is an important capability.

X-ray (Digital). The ability to take x-rays is a current capability at forward areas of care. However, the current methodology is based on chemical development, requiring large amounts of film and developing fluids. A miniaturized digital x-ray device could reduce the need for both film and chemicals. The hazardous waste from the developing fluids used with the current film technology would also be eliminated by the use of a digital x-ray unit. There would also be a timesavings due to the reduced "developing" time.

One problem resulting from the new digital technology would be the reduced ability to take or review images in case of a power failure. The new technology requires a computer for viewing, and this capability would be dependent on battery life in a power failure situation. Although with the current system power is still needed to take and review images, a medical provider can hold a film up to natural lighting for review in a power failure.

All but one of the data sources supported a digital x-ray device as useful (see Table 4). The only data source that did not support the usefulness of this device was the discussion group data. It is possible that these data did not indicate the usefulness of such a device because the SMEs were given information that such capability would be tested in the future.

Defibrillator. Abnormal heart rhythms called arrhythmias cause most sudden cardiac arrests. Ventricular fibrillation is the most common arrhythmia that causes cardiac arrest. It is a condition in which the heart's electrical impulses suddenly become chaotic, often without warning. This causes the heart to stop abruptly. Victims collapse and quickly lose consciousness. Patients being treated at forwards areas may go into cardiac arrest. Three of the five data sources indicated that a defibrillator would be a useful device. The survey, matrices, and AMAL data indicated that a defibrillator would be useful.

Clinical Support Functions

Simultaneous Multi-Patient Monitoring. Management of multiple casualties by limited personnel is perhaps the biggest challenge facing forward and remote resuscitative surgery teams. Casualties

must be evaluated (admitted), prioritized for treatment, treated, stabilized, prioritized for evacuation, and finally evacuated. During transport or mass casualty situations, the ability to monitor multiple casualties is necessary for optimal staff performance. At any time in this process any one patient's condition may deteriorate and require immediate intervention and a shift in priority for treatment and/or evacuation.

The ability to monitor essential physiological information simultaneously on multiple casualties to guide treatment protocols and detect deteriorating casualties would be highly beneficial. Additionally, if a single piece of equipment could provide this capability it would significantly reduce the medical "footprint." During the group discussions, the Marine Corps personnel viewed developing this capability as the most important features for future evolutions for the M3. The Marine Corps personnel said that the multi-patient monitoring capability was one of the most efficient uses of technology for conserving and maximizing critical medical personnel. The ability to simultaneously capture critical patient data for the patient's medical record, especially an electronic patient record, would be very beneficial as well.

Three of the five data sources (see Table 4) indicated that the ability to monitor multiple patients would be beneficial.

Personal Information Carrier (PIC) Reader/Writer (e.g., Smartcard Interface). An inordinate amount of time is required to administratively admit a patient into the health care delivery system. The administrative function of admitting a patient into the health care delivery system is not only time consuming, but is also accomplished in an often hectic and unstable environment during the most critical time of initial patient care, "the Golden Hour." Given that the patient is often admitted during a hectic and unstable environment many errors can be generated.

Three of the five data sources supported the PIC reader/writer. The use of the PIC to initiate an electronic patient record will significantly reduce the amount of administrative time and personnel. The potential error rate will be reduced as well (Galarneau & Wilcox, 1994; and Galarneau & Wilcox, 1993). All of these will in turn enable the medical providers to focus more effort on the casualty and less on administrative paperwork.

Additionally, the "write" capability for recording critical medical information to the PIC is extremely valuable and represents an excellent example of complimenting technologies.

Electronic Patient Record. Although the term "electronic patient record" has not been clearly defined, the ability to electronically document (store) a variety of clinical data (including images) and to transmit (forward) these data over available communication links is a requirement. The speed and accuracy of capturing these data are extremely important in FRS units. Additionally, using "paper" in forward areas creates a plethora of problems (wet, dirty, lost/misplaced paperwork, as well as storage and security problems).

All but one of the data sources (AMAL data) indicated that the ability to create an electronic patient record was an important feature (see Table 4).

Image Capture. Imaging capability allows the capture of images produced by ultrasound (with Doppler), ECG/EKG, Digital x-ray, still images of patients, and a variety of scopes and probes. After capture (storage) the images can be incorporated into an electronic patient record, and then transmitted (forwarded) to a distant location. With imaging capability, it is possible to provide pictorial documentation of before, during, and after treatment.

Four of the five data sources support the imaging capture capability (see Table 4). The consultative possibilities made available by this capability are virtually endless. The M3 (A) currently has this capability.

Global Positioning System. A GPS provides an exact location of where the M3 resides. This information can then be used in conjunction with the name of the admitting unit, the name of the patient, the time of admission of the patient, and treatment of the patient. This GPS location will provide critical information for patient evacuation, regulation, tracking, and record-keeping requirements. The location data could also be used for medical surveillance, preventive medicine, and other epidemiological applications. The potential value of this capability is increased when operating in nuclear, biological, chemical environments.

Only two of the data sources (see Table 4) indicated that GPS capabilities would be useful. A third data source (survey data) was not included as being supportive of this capability because more people felt that it would not be useful than those who did. However, 35% of the people did indicate that it would be useful.

Administration Functions

Medical Management/Store and Forward Capability. This capability allows consultative support to be obtained without requiring the consultant to be immediately available, thus relaxing/easing scheduling constraints. Also, bandwidth demands are considerably less than with traditional Video Teleconferencing (VTC) capability. Traditional VTCs must be planned as well, which is not necessary in the store and forward arena. The FRS medical requirement document was the most supportive data for this capability.

Graphic User Interface (GUI). Survey data indicated that the GUI for the current M3 (A) was good, but that there was some room for improvement. Recommendations have been given to the designers of this software. The GUI improvements will focus on simplifying the operator procedures for recording, managing, and transmitting selected patient data.

Windows NT. None of the data sources indicated that the Windows NT operating system was a necessary requirement for future evolutions of the M3. However, Department of Defense has identified the Windows NT operating system as the Common Operating Environment for

computer systems. The Windows NT operating system provides a powerful, flexible, and efficient mechanism for managing files, drivers, and network connections, and it allows developers to create robust solutions for a variety of applications and devices, essential features for continual integration and expansion of the M3 capability.

Recommendations

The M3 development process is one of evolutionary development wherein an existing ruggedized PC-platform is used as a base system. Existing technology that uses standard interfaces is combined with open systems architecture to rapidly expand the basic PC-platform capabilities for demonstration to potential users. Users then evaluate the demonstrated capabilities based on real, current need and make recommendations for retention of the demonstrated capability as well as additional clinical care enhancement capabilities.

Because this project follows an evolutionary integration of existing technologies into the M3 system, not developing new prototypes, these requirements must be addressed within the context of practical constraints. One of the objectives of the M3 project has been to define a flexible architecture for a deployable, lightweight, portable, ruggedized, highly mobile medical data capture capability. Incorporating the M3 concept at far-forward levels of care should enhance patient diagnosis, treatment, and disposition, decrease the medical footprint and staffing, and maximize returns to duty.

The FMF medical personnel interviewed indicated that multi-patient monitoring capability rated the highest priority. However, it was determined that this capability could not be implemented in the short time frame and was not supported by the existing M3 architecture. Because of the engineering challenge of incorporating the multi-patient monitoring capability into the M3 design a two-pronged development strategy was adopted. One was to develop an M3 (B) without multi-patient monitoring, and a second strategy was to develop a proof of principle for the multi-patient monitoring capability.

Candidate technologies were nominated for inclusion in the M3 using criteria such as its commercial off-the-shelf availability, whether it was FDA approved, the use of standard interfaces, its compatibility with Microsoft Windows NT and its availability within a four to six month window. Therefore, based on these criteria and results presented here it is recommended that for the first approach the clinical functions of the M3 (B) include ultrasound with doppler, ECG monitor with diagnostic software, pulse oximeter, blood pressure, manual temperature input, and nasopharyngeal scope. Ultrasound with Doppler monitoring capability and storing and forwarding the data to evacuation personnel and the receiving/consulting MTF can maximize the value of this capability. Interpretive (also called diagnostic) software for the ECG monitor, along with a store and forward capability, provides significant enhancement to the consultative capability and is vital for robust patient evaluation, treatment, and evacuation. The clinical support functions should include PIC reader/writer, electronic patient record, image capture, and GPS. Further, the administrative functions should include store and forward capability, improved GUI, and Windows NT.

Further, it is recommended that a second strategy of developing a multi-patient monitoring system be pursued. This system should be designed to provide a seamless method of monitoring the vital signs of 4 to 8 casualties continuously from far-forward areas, through patient transport, all the way back to the more definitive levels of care. The current M3 architecture needs to be modified such that clinical data from multiple patients can be acquired, stored, edited, and forwarded. Finally, the key strategy for implementing the mobile medical monitor concept is to continue to work with the users and satisfy their requirements by utilizing existing, evolving and emerging technologies and capabilities.

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Appendix A- Survey Collection Form

DATE: ____________________

Mobile Medical Monitor - M3

This Mobile Medical Monitor (M3) is a portable, ruggedized, diagnostic unit containing medical sensors such as electrocardiogram, blood pressure and pulse oximetry. Please answer the following questions concerning this M3 and how it might be improved to help medical care providers. **The information you provide will be vital for establishing requirements to develop an M3 capability.**

1. Job Title: ____ Doctor ____ Nurse ____ Corpsman ____________ Other (Please specify)

   Rank/Rate: ____ Corps/Rating: ____ Medical Specialty: ____________

2. How long have you been in your current position? [ ] Years [ ] Months
   How long have you worked in the medical field? [ ] Years [ ] Months

3. Did you see this M3 function? ____ Yes ____ No

4. Did you operate this M3? ____ Yes ____ No

5. How many times (number of patients) did you use this M3? ______

6. Where did you observe or use this M3?

   ___Ambulance ___BAS ___Clinic ___Helicopter Other: Please specify ________

For the following section, please circle the appropriate response using the following scale.
VE = Very Easy **E** = Easy **N** = Neither Easy Nor Difficult **D** = Difficult **VD** = Very Difficult

7.	Indicate how easy or difficult it is to **learn** to use this M3 in the scenario indicated in question 6.	**VE**	**E**	**N**	**D**	**VD**
8.	Indicate how easy or difficult it is to **operate** this M3 in the the scenario indicated in question 6.	**VE**	**E**	**N**	**D**	**VD**
9.	Indicate how easy or difficult it is to **understand the data displayed** on this M3 in the scenario indicated in question 6.	**VE**	**E**	**N**	**D**	**VD**
10.	Indicate how easy or difficult it is to **read the data displayed** on this M3 in the scenario indicated in question 6.	**VE**	**E**	**N**	**D**	**VD**

11. Rank order the following five measures in terms of their usefulness in the scenario indicated in question 6 (1 = most useful and 5 = least useful).

____ Blood pressure
____ ECG
____ Oxygen saturation
____ Pulse rate
____ Still images

12. List additional measures that would be useful in the scenario indicated in question 6.

____
____
____
____

13. In what other situations or scenarios would the M3 be useful?

____
____
____

14. Do you like this M3? _____ Yes _____ No

What do you like MOST about this M3? ____________________
____
____
____

What do you like LEAST about this M3? ____________________
____
____
____

15. Indicate other features that should be included in the M3 to make it more useful.

_____ Automatic data upload to patient record
_____ Electronic mail (E-mail)
_____ Global positioning system (GPS)
_____ Internet connectivity
_____ Patient record retrieval from other medical treatment facilities
_____ Smart card reader
_____ Standardized medical reports
_____ Store and forward patient information
_____ Teleconferencing
_____ Teleradiology
_____ Transmit still images
_____ Ultrasound
_____ Other: Please specify ______________________________

16. Which do you like better?

_____ Separate individual instruments and sensors (using current individual instruments)
_____ Integrated monitor containing miniaturized sensors (M3 concept)

Why? ____
____
____

17. Can the M3 improve medical care? _____ Yes _____ No

Why? ____
____
____

18. Please add any additional comments about the M3 here.
____
____
____
____
____
____
____

Thank you for your time and participation. Your comments are vital for establishing requirements to develop a Mobile Medical Monitoring (M3) capability.

Appendix B-Martrix Data Collection Form

DATE: ____________________

Mobile Medical Monitor -- M3

The current Mobile Medical Monitor [M3(A)] is a portable, ruggedized diagnostic unit containing medical sensors such as electrocardiogram, blood pressure and pulse oximetry.

Please fill out the matrices on the following pages concerning the Mobile Medical Monitor concept and how it might be improved to help the medical care provider. **The information you provide will be vital for establishing requirements to develop a Mobile Medical Monitoring (M3) capability.** These requirements are necessary for future development of the Mobile Medical Monitor (M3).

NOTE: There is one matrix for three **DIFFERENT** scenarios. It will take approximately 20 minutes to complete ALL three.

1. Job Title: ___ Doctor ___ Nurse ___ Corpsman ______________ Other (Please specify)

   Rank/Rate: _____
   Corps/Rating: _____

   Medical Speciality: ______________________

2. How long have you been in your current position? [ ] Years [ ] Months

   How long have you worked in the medical field? [ ] Years [ ] Months

Mobile Medical Monitor -- M3

This page is an **EXAMPLE** of how the matrices are to be filled out. Please review and then complete the following matrices.

Please review the following table and then rank order the priority level of **each** medical tool, sensor, or measurement across **each** level of care based on the given Mission. (Where 1 is the highest priority, 2 is the second highest priority, etc. For the medical tools, sensors, or measurements that are **NOT APPLICABLE** for the given mission please indicate by putting a **- (dash)** in their boxes. **Please do not leave any spaces blank.**)

MISSION: OMFTS (Operational Maneuvers from the Sea: Small Footprint)

Level of Care	Blood Type	Blood Cross Type	Blood Chemistry	Blood Pressure	O_2 Saturation	Heart Rate	Cardiac Output	Cardiac Monitor Alarm	Defibrillator	Respiratory Rate	Thermometer	Glucose Monitor	PH Sensor	X-Ray	Video Imaging	Ultrasound	Pathology	Electronic Stethoscope	Marc Card Reader	Patient Location	Environmental Monitor	Data Transfer via modem	Manual data input	Other *
Front Line	-	-	-	1	-	2	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	4	5	
Battalion Aid Station	-	-	-	1	-	2	-	9	10	3	-	-	-	8	-	11	-	-	6	7	-	4	5	
Shock Trauma Platoon																								
Surgical Company																								
Other*	10	11	3	5	4	6	-	-	12	7	-	-	-	1	-	2	-	-	8	13	14	15	9	

*PLEASE SPECIFY "Other Level of Care" Evacuation Station and
"Other Medical Tools, Sensors, and Measurements" None

Additional Comments: For "defibrillator"above I am referring to an automatic one. Under "environmental monitor" above I mean a CBR (Chemical,Biological, and Radiological) monitor I did not fill out for "Shock Trauma Platoon" or "Surgical Company" because I don't think there would be these in an OMFTS. Configure the M3 at Evac Station, CRTS & LCAC same as surgical company.

Mobile Medical Monitor -- M3

Please review the following table and then rank order the priority level of **each** medical tool, sensor, or measurement across **each** level of care based on the given Mission. (Where 1 is the highest priority, 2 is the second highest priority, etc. For the medical tools, sensors, or measurements that are **NOT APPLICABLE** for the given mission please indicate by putting **N/A** in their boxes. Please **do not leave any spaces blank.)**

MISSION: STANDARD COMBAT

		Medical Tools, Sensors and Measurements																							
		Blood Type	*Blood Cross Type*	*Blood Chemistry*	*Blood Pressure*	*O_2 Saturation*	*Heart Rate*	*Cardiac Output*	*Cardiac Monitor Alarm*	*Defibrillator*	*Respiratory Rate*	*Thermometer*	*Glucose Monitor*	*PH Sensor*	*X-Ray*	*Video Imaging*	*Ultrasound*	*Pathology*	*Electronic Stethoscope*	*Marc Card Reader*	*Patient Location*	*Environmental Monitor*	*Data Transfer via modem*	*Manual data input*	**Other ***
Level of Care	*Front Line*																								
	Battalion Aid Station																								
	Shock Trauma Platoon																								
	Surgical Company																								
	Other*																								

***PLEASE SPECIFY** "Other Level of Care" ____________ and
"Other Medical Tools, Sensors, and Measurements" ____________

Additional Comments:____

Mobile Medical Monitor -- M3

Please review the following table and then rank order the priority level of **each** medical tool, sensor, or measurement across **each** level of care based on the given Mission. (Where 1 is the highest priority, 2 is the second highest priority, etc. For the medical tools, sensors, or measurements that are **NOT APPLICABLE** for the given mission please indicate by putting **N/A** in their boxes. Please **do not leave any spaces blank.**)

MISSION: OOTW (OPERATIONS OTHER THAN WAR)																									
		Medical Tools, Sensors and Measurements																							
		Blood Type	*Blood Cross Type*	*Blood Chemistry*	*Blood Pressure*	*O_2 Saturation*	*Heart Rate*	*Cardiac Output*	*Cardiac Monitor Alarm*	*Defibrillator*	*Respiratory Rate*	*Thermometer*	*Glucose Monitor*	*PH Sensor*	*X-Ray*	*Video Imaging*	*Ultrasound*	*Pathology*	*Electronic Stethoscope*	*Marc Card Reader*	*Patient Location*	*Environmental Monitor*	*Data Transfer via modem*	*Manual data input*	**Other ***
Level of Care	*Front Line*																								
	Battalion Aid Station																								
	Shock Trauma Platoon																								
	Surgical Company																								
	Other*																								

***PLEASE SPECIFY** "Other Level of Care" ____________ and "Other Medical Tools, Sensors, and Measurements" ____________

Additional Comments:______________________________

Mobile Medical Monitor -- M3

Please review the following table and then rank order the priority level of **each** medical tool, sensor, or measurement across **each** level of care based on the given Mission. (Where 1 is the highest priority, 2 is the second highest priority, etc. For the medical tools, sensors, or measurements that are **NOT APPLICABLE** for the given mission please indicate by putting **N/A** in their boxes. Please **do not leave any spaces blank.**)

MISSION: OMFTS (OPERATIONAL MANEUVERS FROM THE SEA: Small Footprint)

		Medical Tools, Sensors and Measurements																							
		Blood Type	*Blood Cross Type*	*Blood Chemistry*	*Blood Pressure*	*O_2 Saturation*	*Heart Rate*	*Cardiac Output*	*Cardiac Monitor Alarm*	*Defibrillator*	*Respiratory Rate*	*Thermometer*	*Glucose Monitor*	*PH Sensor*	*X-Ray*	*Video Imaging*	*Ultrasound*	*Pathology*	*Electronic Stethoscope*	*Marc Card Reader*	*Patient Location*	*Environmental Monitor*	*Data Transfer via modem*	*Manual data input*	**Other ***
Level of Care	*Front Line*																								
	Battalion Aid Station																								
	Shock Trauma Platoon																								
	Surgical Company																								
	Other*																								

***PLEASE SPECIFY** "Other Level of Care" ____________ and
"Other Medical Tools, Sensors, and Measurements" ____________

Additional Comments:____________________

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13. ABSTRACT *(Maximum 200 words)* The nature of the U. S. Marine Corps mission is changing. In addition to combat operations, Marines are increasingly committed to a broader range of support scenarios and operations other than war. These commitments require medical support, often in remote and austere environments. New and emerging technologies can be used to prepare responders for this challenge. Mobile medical monitoring for forward deployed forces could be used to perform continuous monitoring of patients while they are waiting to be treated and evacuated. The objective of this report was to document the requirement and potential uses for mobile medical monitoring in support of specified U.S. Marine operational scenarios. Multiple data sources were used for determining the requirements for future evolutions of a mobile medical monitor capability. Medical doctrine and policy and medical resource requirements were reviewed and user feedback was gathered using surveys and discussion groups. The results revealed several requirements for a M3 capability. ECG monitor, pulse oximeter, blood pressure, temperature, ultrasound, and digital x-ray were recommended as clinical functions, while multi-patient monitoring. Smartcard reader/writer, electronic patient record, and image capture were mentioned as clinical support functions. The ability to store and transmit patient information was also indicated as a beneficial capability for use by medical personnel in forward areas of care.

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